Boeing Mid-IR BIB FPA Technology

Presented to:
NGST Annual Technology Challenge Review #1
NASA/Goddard Space Flight Center
July 7-10, 1997

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Partially Sponsored by: " Si:As and Si:Sb Arrays for SIRTF", Subcontract No. OSP27136-5403, Cornell University

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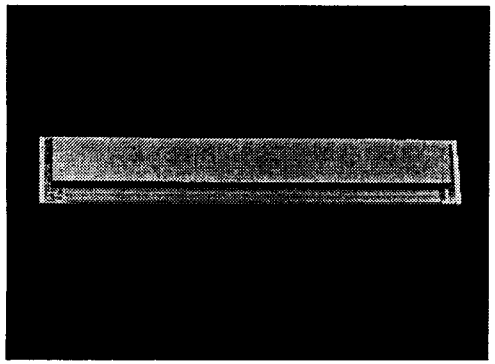
Introduction and Outline

- Blocked-Impurity-Band (BIB) HFPA Background
- BIB Detector Summary
- Multiplexers for BIB HFPAs
- BIB HFPA Performance
- Future BIB HFPA Development

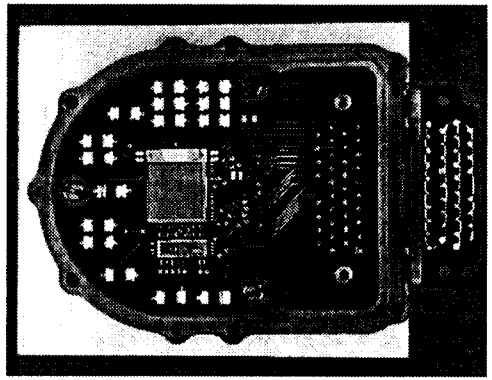
Background

- Si:As Blocked-Impurity-Band (BIB) Detectors & HFPAs Provide Capability to Reach NGST Wavelength Range Goal
  - Si:As responds to $\lambda \sim 30\ \mu m$
  - Excellent low-background performance, uniformity & operability
- Boeing BIB Arrays Are Proven for Space Missions
  - Flown on SPIRIT II, SPIRIT III/MSX (10x25, 8x192 arrays)
  - Flight hardware delivered for Wide-Field Infrared Explorer (2-128^2 arrays)
  - Flight hardware build initiated for SIRTF IRS & MIPS (5-128^2 arrays -Si:As and Si:Sb)

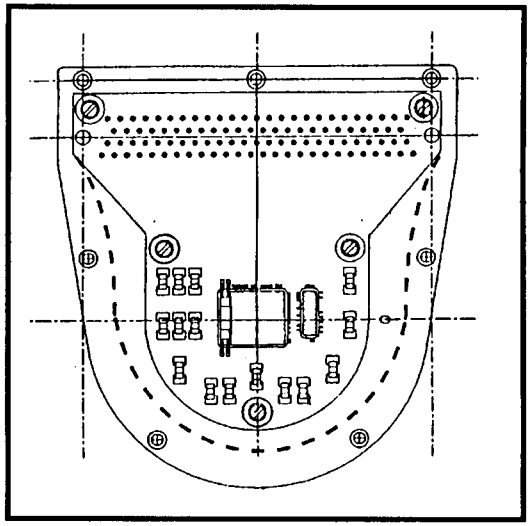
Boeing BIB Focal Planes for Space



SPIRIT III (1996)



Wire (1998)



SIRTF (2001)

- Mounts for Interface to Cryogenics, Cryogenic Cabling and Flight Electronics also Developed

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Background (Cont)

- 128^2 BIB Arrays Have Been Optimized for a Wide Range of Applications
  - High-flux arrays for passive seekers/ground-based astronomy
  - Moderate-flux arrays plus switchable integration capacitance
  - Low-flux arrays for space
  - Si:As and Si:Sb Detectors
- BIB HFPA Technology Has Been Extended to 256^2 Format
  - 50 μm x 50 μm pixels
  - First application - high-flux, passive seekers

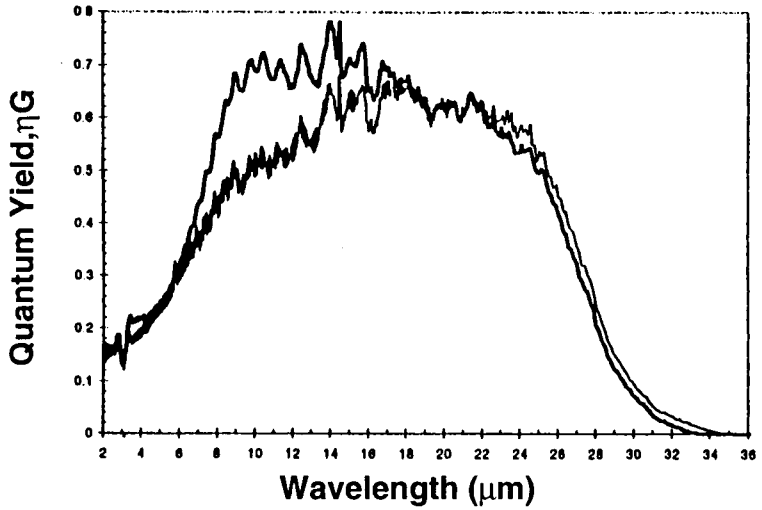
Provides Technology Base Supporting Continued BIB HFPA Evolution and Refinement to Meet NGST Goals

Si:As BIB Detectors

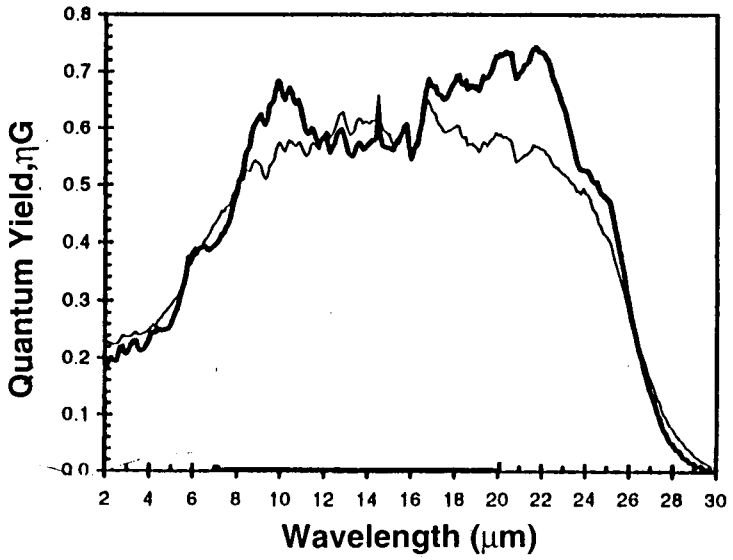
- Silicon Epitaxial Technology Developed to Provide High-Quality, Uniform, Large-Area Detector Arrays
  - $\leq$ 2% responsivity non-uniformity (σ /μ)
  - > 99.9% operability
- Anti-Reflection (AR) Coating Technology Successfully Applied
  - QE improvement for imaging
  - Interference fringe (channeling) reduction for spectroscopy
  - Further improvements are being pursued
- Additional Detector Properties Are Covered in a Companion Paper

AR Coating Results

10 μm AR Coating



25 μm AR Coating



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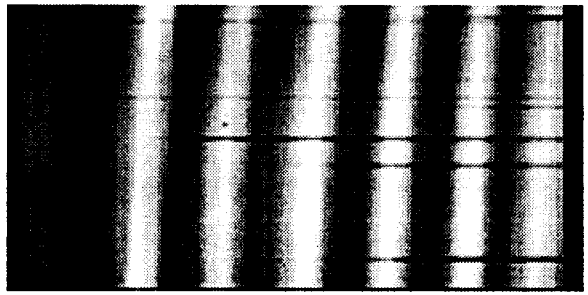
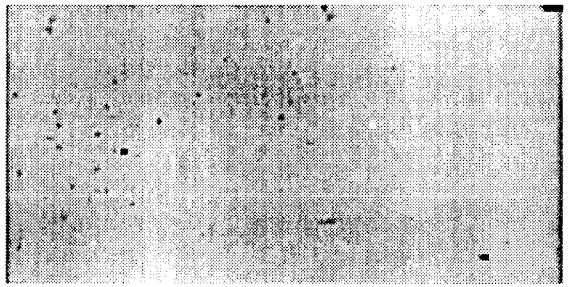
Fringe Suppression with AR Coating

No AR Coating λ_m = 8.99 μm



AR Coating for λ = 9.6 μm λ_m =11.7 μm



Data Courtesy of Tom Hayward, Cornell University

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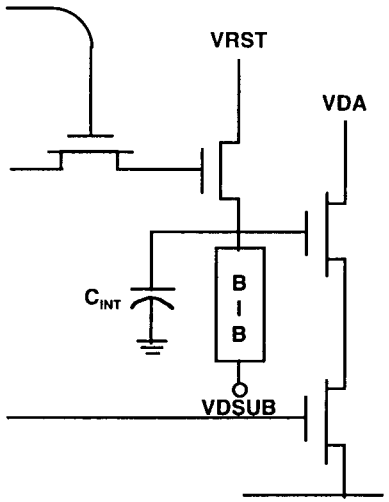
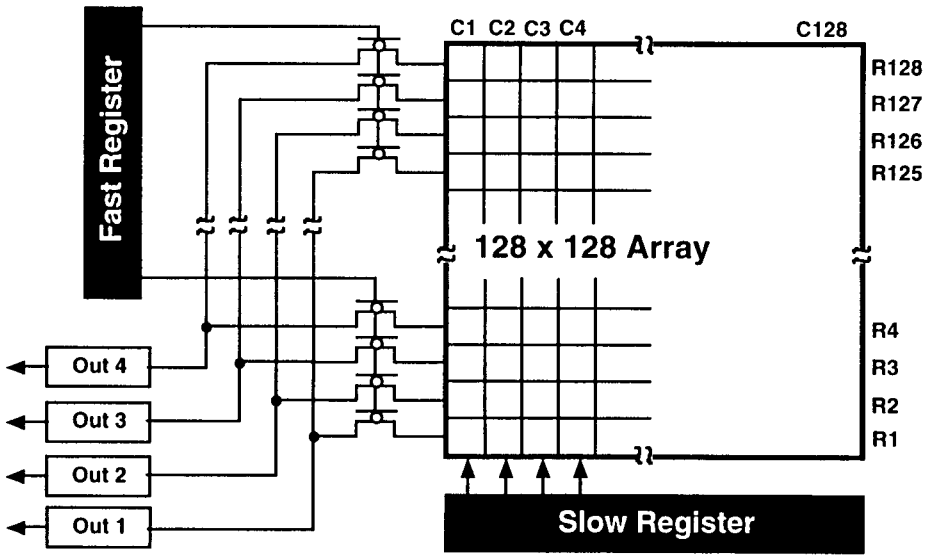
Multiplexers for BIB HFPAs

- 128 x 128-element Multiplexer for Space Missions (WIRE, SIRTF)
  - 75 μm x 75 μm direct readout unit cell size
  - Four outputs
  - Non-destructive read capability for multiply sampled readout
  - C_{eff} = 0.13 pF
  - Boeing 2 μm Cryogenic CMOS process (Orbit Semiconductor)



Unitcell



Layout

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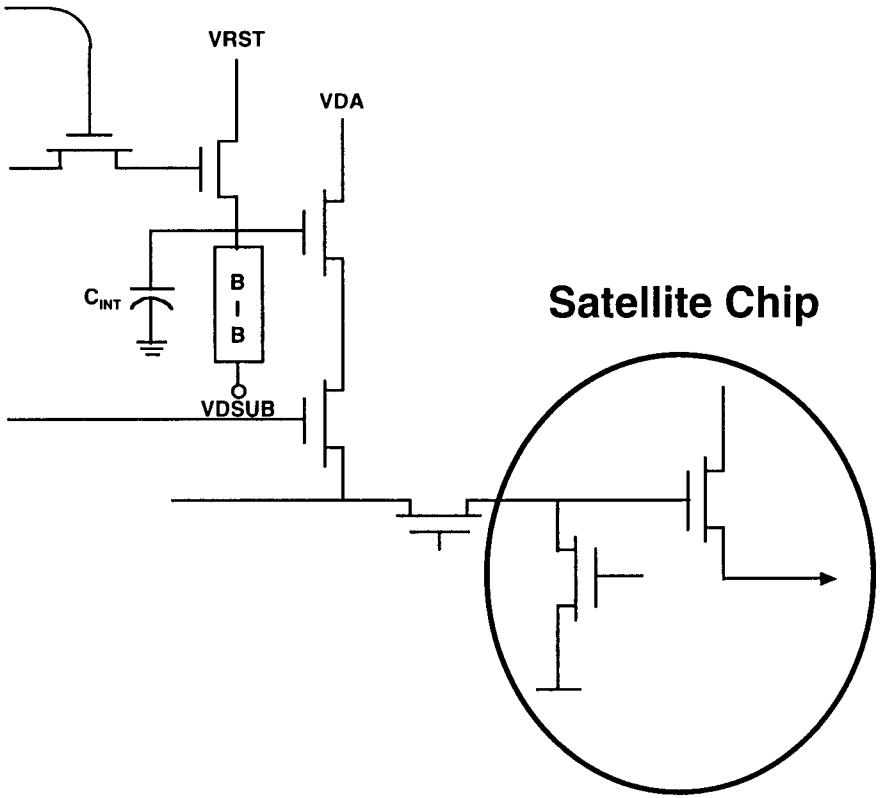
"Satellite" Chip

- Developed and Used to Eliminate Glow (Photon Emission) Detected from Multiplexer Circuits
- Separate Chip Which Contains Internal Current Source Loads, Output Drivers, Clock Buffer Circuits



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128^2 BIB HFPA Data Summary

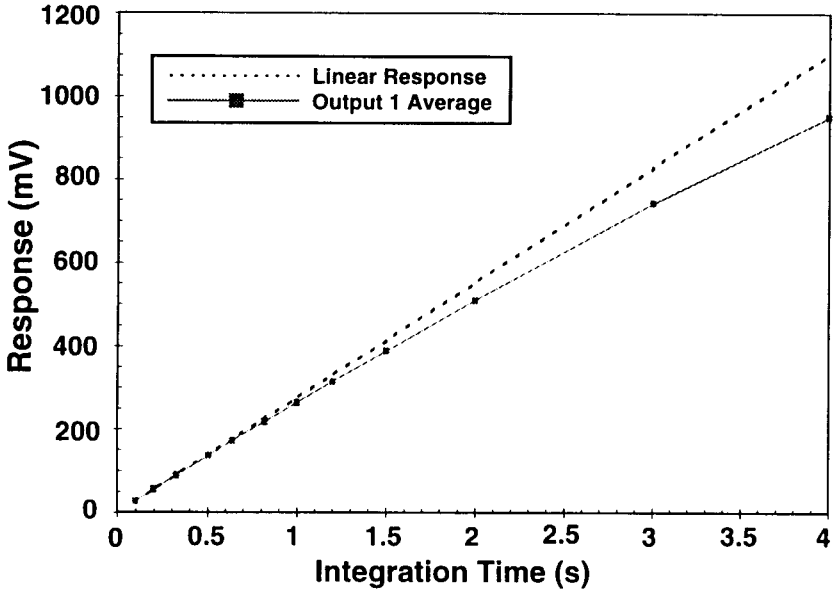
T ~ 7.5 K **T_{int} = 4 s** **Detector Bias = 1.5 V**

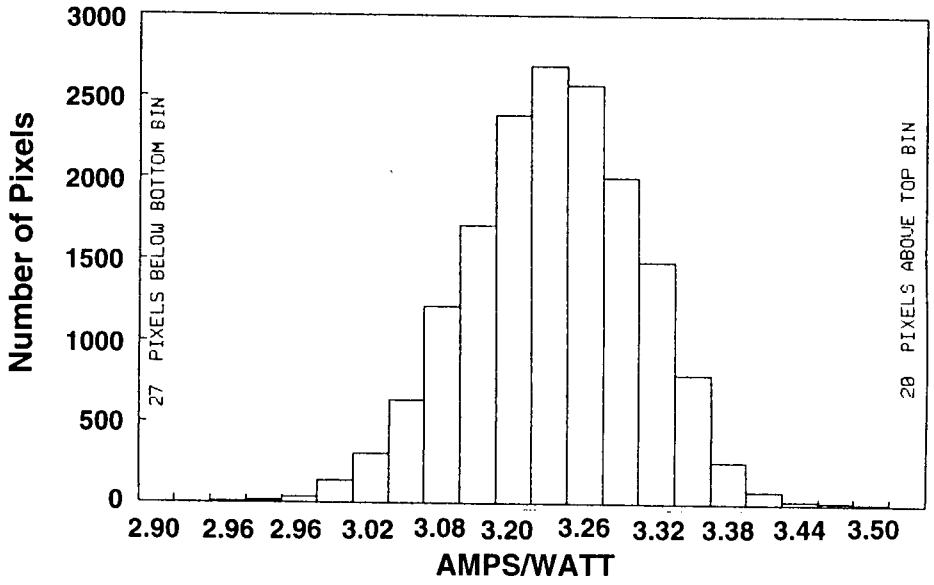
Measurement Wavelength	FPMA Number	Detector Split	Read Noise (erms)	Responsivity (A/W)	NEI (ph/s)	DQE	Operability (%)	Non-Uniformity (%)	Dark Current (e/s/pixel)
11.6 μm	9	A	56	6.8	94	0.79	99.70	4.1	13
	10	B	54	6.3	98	0.78	99.90	3.8	197
	11	B	57	6.3	105	0.84	99.40	3.2	–
20.6 μm	8	A	52	11.0	107	0.87	99.80	4.0	33
	6	B	55	8.7	117	0.71	99.80	3.2	292
	7	B	52	9.8	96	0.82	98.90	3.7	–

* Influenced by Spurious Reflection

- **Sampling up the Ramp Measurements Made by Cornell University**
  - **T = 4.2 K, T_{int} > 600 s**
  - **Equivalent Read Noise = 20 erms**
  - **Dark Current < 10 e/s-pixel**

128^2 HFPA Data





Output vs. Integrated Charge

10 % Linearity at

$6x10^5$ e/well

Responsivity Histogram

Non-uniformity = 2.0%

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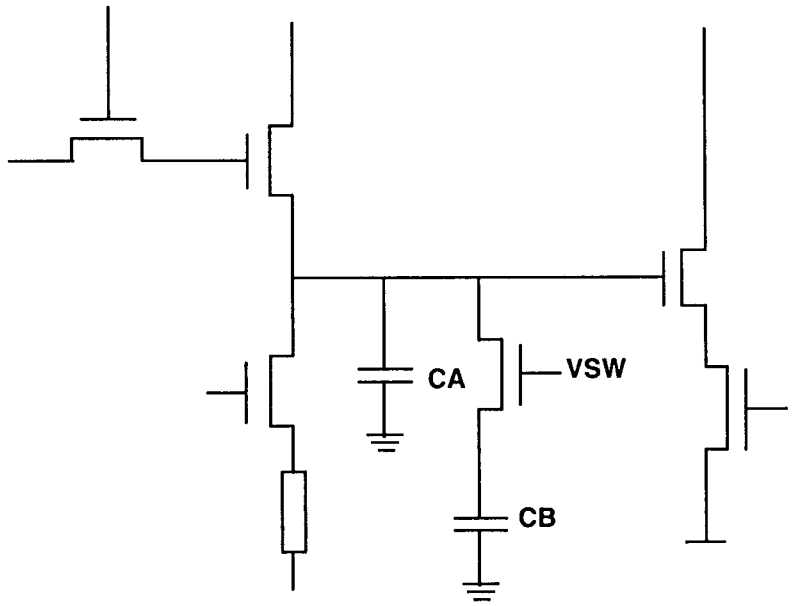
Switchable Integration Capacitance Unit Cell

- Optimizes Sensitivity and Well Capacity for Combined Imaging and Spectrometer Applications



- Boeing's First 256x256-element BIB Arrays for Low/ Moderate Flux will use this Design
  - 50 μm x 50 μm unit cells
  - C_{eff} =0.225 pF or 3.6 pF

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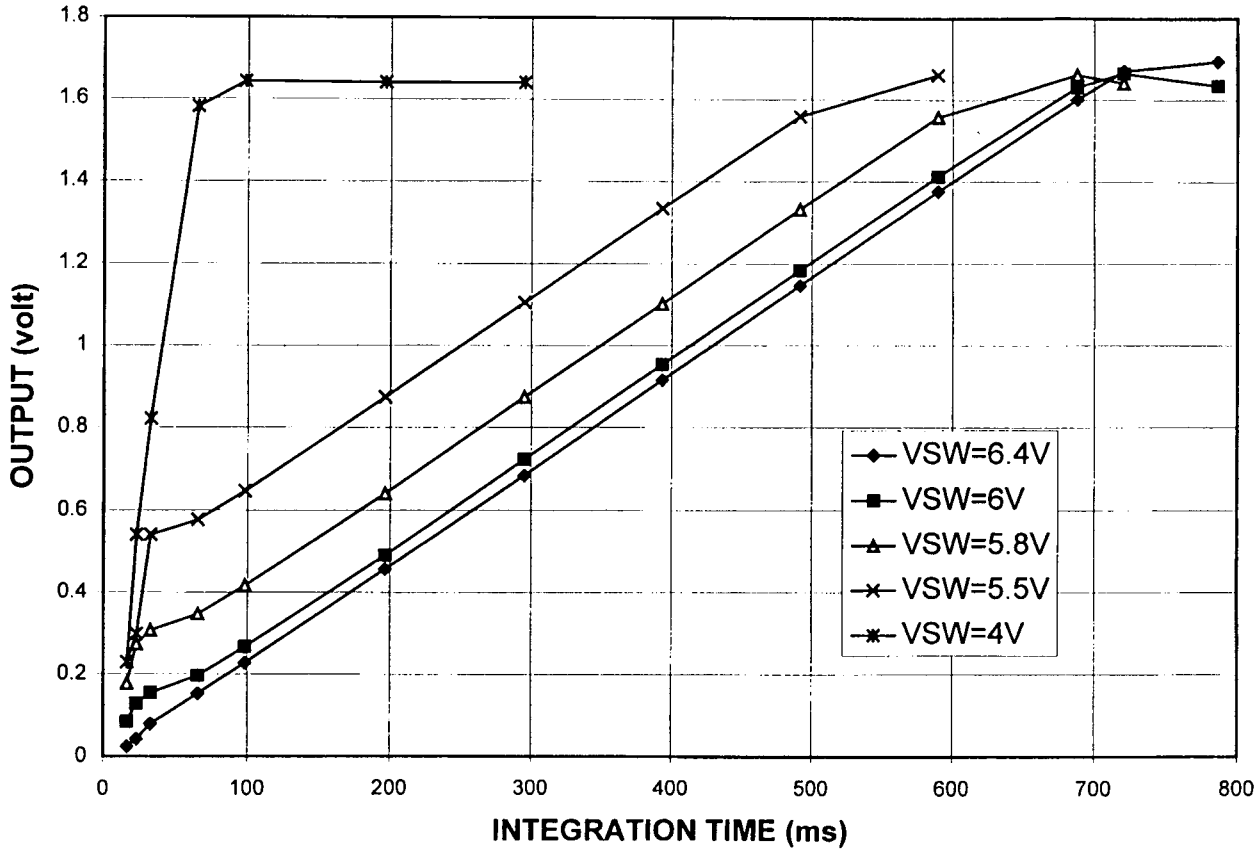
Switchable Integration Capacitance Results

T=5 K Bias = 2.0 V Flux = 10^{12} ph/cm^2-s @ 10.6 μm



C_{eff} = 0.17 or 1.75 pF

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256^2 BIB HFPAs Have Been Demonstrated

- First Devices Are for High-Flux, Seeker Applications
- High Multiplexer Fabrication Yield Achieved
  - 0.6 μm CMOS, 0.8 μm SOI CMOS processes used with minimal changes
  - Advantages of state-of-the-art silicon processes are retained (high yield, availability, etc)
- 256^2 Multiplexer Functional Yield of 65% Achieved with First 0.6 μm CMOS Lot
- 256^2 BIB HFPAs Are Fully Functional, Undergoing Test and Optimization

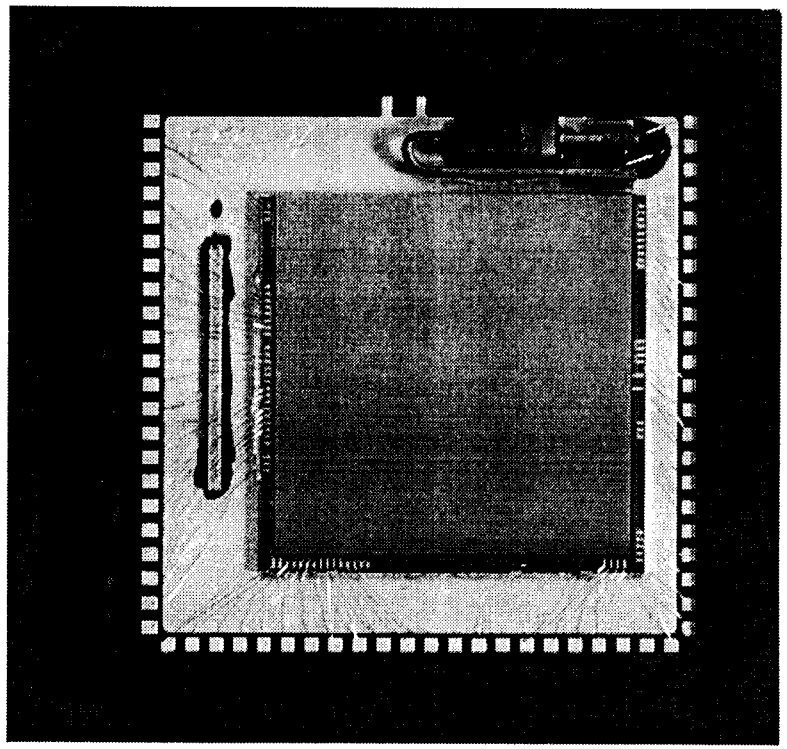
256^2 BIB HFPA Features

16 Outputs @ 4 Mpix/s
(1000 Frames/s)

50 μm x 50 μm Direct
Injection Unit Cells

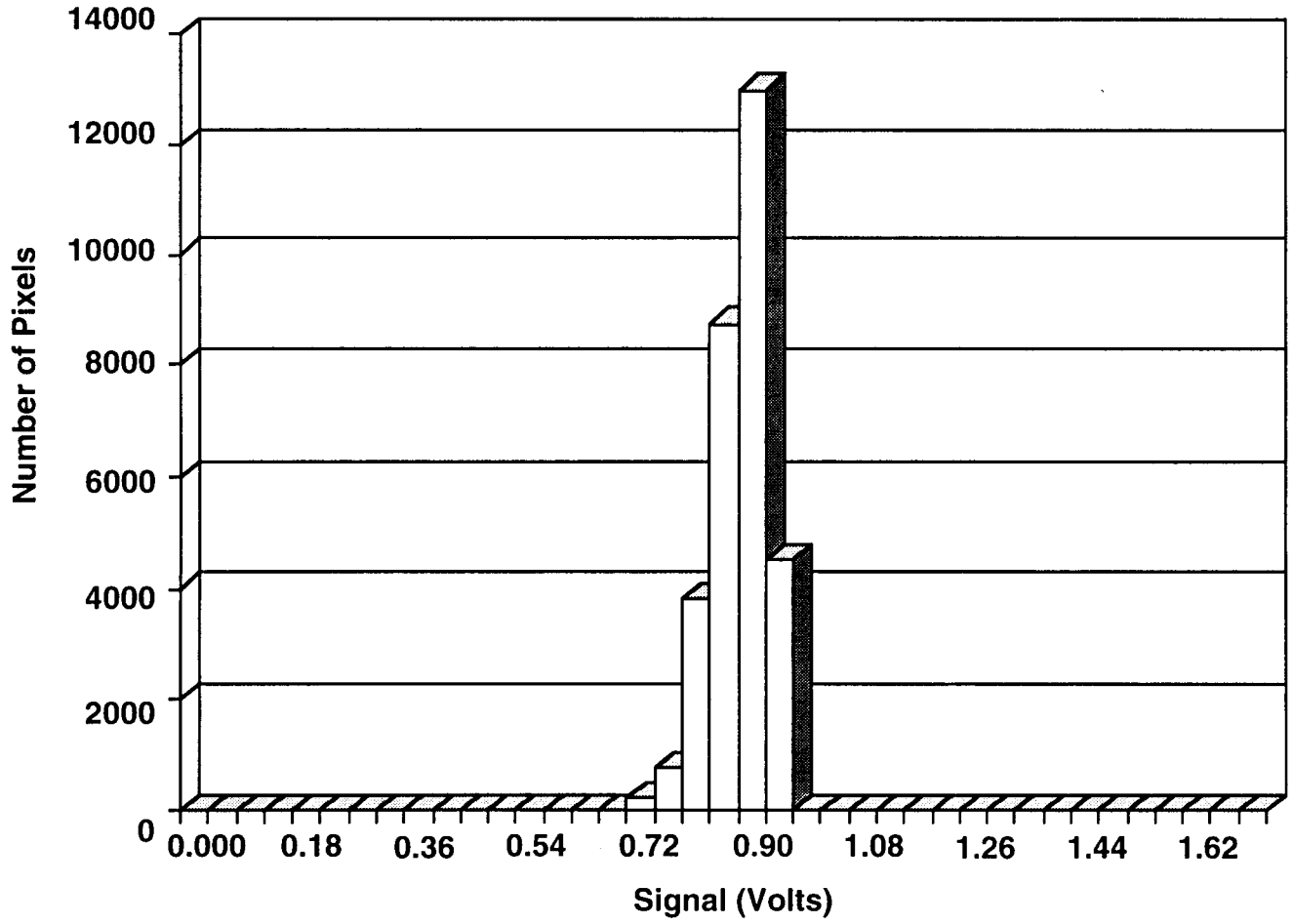
Variable Integration Time

Charge Capacity
2.2×10^7 e/well



256^2 BIB HFPA Signal Histogram

T = 12 K T_{int} = 975 μs Flux ~ $7x10^{14}$ ph/cm^2-s



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Si:As BIB HFPAs for NGST

- Desired array characteristics for MIR (6/97 NGST Study Team)
  - 1000 x 1000 – element array (Mosaic of 512 x 512)
  - 27 μm x 27 μm pixels
  - <15 e/read single sampling readout noise
  - >6 x 10^4 e/well capacity
  - <12 s readout time for entire array
  - <1 e/s/pixel dark current at T = 6-8 K
  - >50% quantum efficiency
- Multiplexer Array, Pixel Sizes Are Achievable with Present Sub-Micron Silicon Processes
  - Direct readout unit cell
  - Present photolithographic limit is ~650^2 elements for 27 μm cell
  - Development with Existing Silicon Processes Provides Cost, Yield and Availability Advantages

Si:As BIB HFPAs for NGST

- Greatest challenge is readout noise – achievable with
  - Direct readout unit cell
  - Off-chip CDS
  - Design/layout optimization for deep cryogenic operation
- No performance barriers are forseen
  - > $6X10^4$ e/well, pixel readout time ~12μs are readily achievable

Si:As BIB HFPA for NGST Can Be Realized with Reasonable Development Resources

Summary and Conclusions

- Boeing 128 x 128-element Si:As BIB HFPA Technology is Mature and Proven in Space
- Boeing Has Demonstrated 256 x 256-element BIB HFPAs
- A Broad Funding Base for BIB HFPAs (DoD, NASA, other) Exists at Boeing to Support Continued Development and Evolution

NGST's Long-wavelength IR Requirements Can Be Met Using Si:As BIB HFPA Technology